Photometric study of new southern SU UMa-type dwarf novae – II: Authentication of BF Ara as a Normal SU UMa-type Dwarf Nova with the Shortest Supercycle

Taichi Kato[1], Greg Bolt[2], Peter Nelson[3], Berto Monard[4], Rod Stubbings[5], Andrew Pearce[6], Hitoshi Yamaoka[7], Tom Richards[8]

[1] *Department of Astronomy, Faculty of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502 Japan*
[2] *295 Camberwarra Drive, Craigie, Western Australia 6025, Australia*
[3] *RMB 2493, Ellinbank 3820, Australia*
[4] *Bronberg Observatory, PO Box 11426, Tiegerpoort 0056, South Africa*
[5] *19 Greenland Drive, Drouin 3818, Victoria, Australia*
[6] *32 Monash Ave, Nedlands, WA 6009, Australia*
[7] *Faculty of Science, Kyushu University, Fukuoka 810-8560, Japan*
[8] *Woodridge Observatory, 8 Diosma Rd, Eltham, Vic 3095, Australia*

Accepted. Received; in original form

ABSTRACT

We photometrically observed the 2002 August long outburst of BF Ara. The observation for the first time unambiguously detected superhumps (average period 0.08797(1) d), qualifying BF Ara as a genuine SU UMa-type dwarf nova. An analysis of the long-term visual light curve yielded a mean supercycle length of 84.3(3) d. The characteristics of outbursts and superhumps more resemble those of usual SU UMa-type dwarf novae rather than those of ER UMa stars. BF Ara is thus confirmed to be the usual SU UMa-type dwarf nova with the shortest known supercycle length. There still remains an unfilled gap of distributions between ER UMa stars and usual SU UMa-type dwarf novae. We detected a zero period change of the superhumps, which is quite unexpected from our previous knowledge. This discovery implies that a previous interpretation requiring a low $\dot{M}$ would be no longer valid, or that a different mechanism is responsible for BF Ara. We propose that the reduced (prograde) apsidal motion of the eccentric disk by pressure forces may be responsible for the unusual period change in BF Ara.

Key words: accretion: accretion disks — stars: cataclysmic — stars: dwarf novae — stars: individual (BF Ara)

1 INTRODUCTION

ER UMa stars are still an enigmatic subgroup of SU UMa-type dwarf novae (for a review of dwarf novae and SU UMa-type dwarf novae, see Osaki (1996) and Warner (1995), respectively). Although most of SU UMa-type dwarf novae have supercycle lengths (T_s: the interval between successive superoutbursts) long than ∼100 d (cf. Nogami et al. 1997), ER UMa stars have extremely short T_s (19–50 d, for a review, see Kato et al. 1999). Only five definite members have been discovered: ER UMa (Kato & Kunjaya 1995; Robertson et al. 1995; Misselt & Shafter 1995); V1159 Ori (Nogami et al. 1995; Patterson et al. 1995); RZ LMi (Robertson et al. 1995; Nogami et al. 1995); DI UMa (Kato et al. 1996); and IX Dra (Ishioka et al. 2001).

From the theoretical standpoint, ER UMa stars pose difficult and interesting problems. The outburst mechanism of SU UMa-type dwarf novae is now widely believed to be a combination of thermal and tidal instabilities in the accretion disk (Osaki 1989). A smooth extension of SU UMa-type dwarf novae toward higher mass-transfer rates ($\dot{M}$) seems to be a natural explanation of extremely short T_s in ER UMa stars (Osaki 1995a). This explanation, however, requires a poorly understood mechanism to prematurely quench superoutbursts to reproduce the extremely short T_s (∼19 d) in RZ LMi (Osaki 1995b).

The origin of the supposed high mass-transfer rates is also a mystery, since the mass-transfer is mainly driven by gravitational wave radiation in SU UMa-type dwarf novae, within the standard evolutionary framework of cataclysmic variables (CVs) (Rappaport et al. 1982, 1983; for recent reviews of CV evolution, see King 1988, 2000).

Several attempts have been made to ascribe such a high $\dot{M}$ to a nova-induced enhancement of mass-transfer (originally discussed in Nogami et al. (1995) in the context of "nova hibernation" scenario: Shara et al. 1986). Recent model calculations, however, have not been successful to reproduce the supposed wide $\dot{M}$ diversity in short-period systems to which ER UMa stars belong (Kolb et al. 2001). An irradiation-induced, cyclic mass-transfer variation has been shown to be also less effective in short-period systems (King et al. 1995, 1996; McCormick 1998, see also a general discussion in Patterson 1998).

Most recently, several ideas have been proposed to explain the unusual outburst properties of ER UMa stars. Hellier (2001) proposed an idea to explain the ER UMa-type phenomenon by considering a decoupling between the thermal and tidal instabilities. Buat-Ménard et al. (2001) tried to explain the ER UMa-type phenomenon by introducing an inner truncation of the accretion disk and irradiation on the secondary star. These ideas either require a still poorly understood mechanism or an arbitrary parameter selection, which does not yet seem to reasonably reproduce observations (Buat-Ménard & Hameury 2002).

From the observational side, the distribution of $T_{\rm s}$ seems to be discontinuous between ER UMa stars and usual SU UMa-type dwarf novae (c.f. Nogami et al. 1997; Hellier 2001). Furthermore, the distribution of the orbital periods ($P_{\rm orb}$) or superhump periods ($P_{\rm SH}$) of ER UMa stars strongly concentrates in a short-period region (Ishioka et al. 2001). These observational properties have raised the following central problems: (1) Do ER UMa stars and usual SU UMa stars comprise a continuous distribution of $T_{\rm s}$? and (2) Are there long-$P_{\rm orb}$ (or long-$P_{\rm SH}$) ER UMa stars? These fundamental questions have not been yet answered. The second question is particular important because the working hypotheses by Hellier (2001) and Buat-Ménard et al. (2001) either require a small binary mass-ratio ($q = M_2/M_1$) or a short orbital period, which would enable a weak tidal torque or a strong effect of irradiation, respectively.

From these motivations, a search for transitional objects between ER UMa stars and usual SU UMa-type stars, and long-$P_{\rm orb}$ ER UMa stars has been undertaken. CI UMa ($T_{\rm s} \sim 140$ d) was once claimed to be a transitional object (Nogami & Kato 1997), but the pattern of its outbursts is much more irregular than those of ER UMa stars. A short $T_{\rm s}$ (89 d) system, V503 Cyg (Harvey et al. 1995) is also unusual in its infrequent normal outbursts.[1] Low-amplitude SU UMa-type dwarf nova, HS Vir, which has similar properties to ER UMa stars in its high frequency of normal outbursts (Kato et al. 1995, 1998), has recently confirmed to have a long ($T_{\rm s}$ = 186 or 371 d, Kato et al. 2001) supercycle, which is unlike those of ER UMa stars. Most recently, SS UMi ($T_{\rm s}$ = 84.7 d, Kato et al. 2000) has been shown to be the shortest $T_{\rm s}$ system having usual properties of SU UMa-type dwarf novae (Kato et al. 1998). A search for transitional objects or long-$P_{\rm orb}$ ER UMa has been unsuccessful.

[1] Kato et al. (2002) reported the detection of a dramatic changes in the outburst pattern of V503 Cyg. V503 Cyg may be a system with two distinct states (the states with low or high number of normal outbursts), both of which are unlike those of ER UMa stars.

Table 1. Observers and Equipment.

Observer	Telescope	CCD	Software
Bolt	25-cm SCT	ST-7	MuniPack[a]
Nelson	32-cm reflector	ST-8E	AIP4Win
Monard	30-cm SCT	ST-7E	AIP4Win

[a] http://munipack.astronomy.cz.

BF Ara is a dwarf nova having a range of variability 13.6 – (16.0p and a tentative classification of an SS Cyg-type dwarf nova according to the 4-th edition of the General Catalogue of Variable Stars (Kholopov et al. 1985). Bruch (1983) photometrically studied this object during an outburst, and recorded 0.25-mag variations which could be attributed to a superhump. However, because of the lack of a sufficiently long series of photometry and the lack of knowledge in the outburst properties, this object has been largely neglected in the past studies. In the most recent years, Kato et al. (2001) noticed the presence of a clear recurring periodicity of long outbursts (likely superoutbursts). From an analysis of the visual observations reported to the VSNET Collaboration,[2] Kato et al. (2001) proposed a mean supercycle length of 83.4 d, on the presumed assumption that BF Ara is an SU UMa-type dwarf nova. Since this supercycle length broke the shortest record among usual SU UMa-type dwarf novae, BF Ara has been regarded as a key object to study the borderline and the relation between usual SU UMa-type dwarf novae and ER UMa stars. The next important step has undoubtedly been an unambiguous detection of superhumps which authenticates BF Ara as a genuine SU UMa-type dwarf nova. We conducted a photometric campaign during a long outburst in 2002 August as an intensive project of the VSNET Collaboration (Kato et al. 2002).

2 OBSERVATIONS

2.1 CCD Observations

The observers, equipment and reduction software are summarized in Table 1. All observers performed aperture photometry implemented in the packages listed in Table 1. The observations used unfiltered CCD systems having a response close to Kron-Cousins $R_{\rm c}$ band for outbursting dwarf novae. The errors of single measurements are typically less than 0.01–0.03 mag. The magnitudes were determined relative to GSC 8347.944, whose constancy during the observation was confirmed by a comparison with GSC 2.2 S230002154022. The relative magnitudes by PN using the primary comparison star of GSC 8347.1475 have been converted to the common scale by adding a constant of −0.691 mag.

Barycentric corrections to the observed times were applied before the following analysis.

[2] http://www.kusastro.kyoto-u.ac.jp/vsnet/.

Table 2. Journal of the 2002 CCD photometry of BF Ara.

2002 Date		Start–End[a]	Exp(s)	N	Obs[b]
August	18	52504.961–52505.055	90	76	N
	18	52504.985–52505.210	30–45	384	B
	19	52505.973–52506.228	60	317	B
	20	52506.952–52507.230	60	339	B
	21	52507.988–52508.224	60	297	B
	22	52509.044–52509.100	240	22	N
	23	52510.201–52510.442	50	312	M
	25	52511.939–52512.092	210	67	N
	26	52512.883–52513.069	180	69	N
	27	52513.889–52514.026	200	53	N

[a] BJD−2400000.
[b] N (Nelson), B (Bolt), M (Monard)

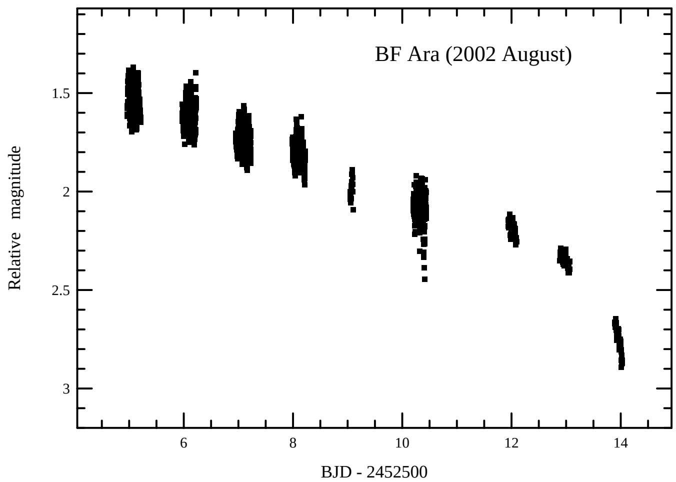

Figure 1. Light curve of the 2002 August superoutburst of BF Ara. The magnitudes are given relative to GSC 8347.944 (approximate USNO A2.0 r magnitude 12.4), and are on a system close to R_c.

2.2 Visual Observations

Visual observations were done with 32-cm (RS), 40-cm (AP), 32-cm (PN) and 32-cm (BM) reflectors. All observations were done using photoelectrically calibrated V-magnitude comparison stars. The typical error of visual estimates was 0.2 mag. The observations were used to determine the outburst cycle lengths and characteristics. CCD monitoring observation by TR (18-cm refractor and an unfiltered ST-7E) has been included in the analysis.

3 THE 2002 AUGUST SUPEROUTBURST

3.1 Course of Outburst

The 2002 August outburst was detected by RS on August 14.415 UT at a visual magnitude of 14.4. The object was reported to be fainter than 14.8 on August 13.491 UT. The object further brightened to a magnitude of 14.0 on August 16.478 UT. Because the outburst was apparently a long, bright outburst (likely superoutburst), we initiated a CCD photometric campaign through the VSNET Collaboration.

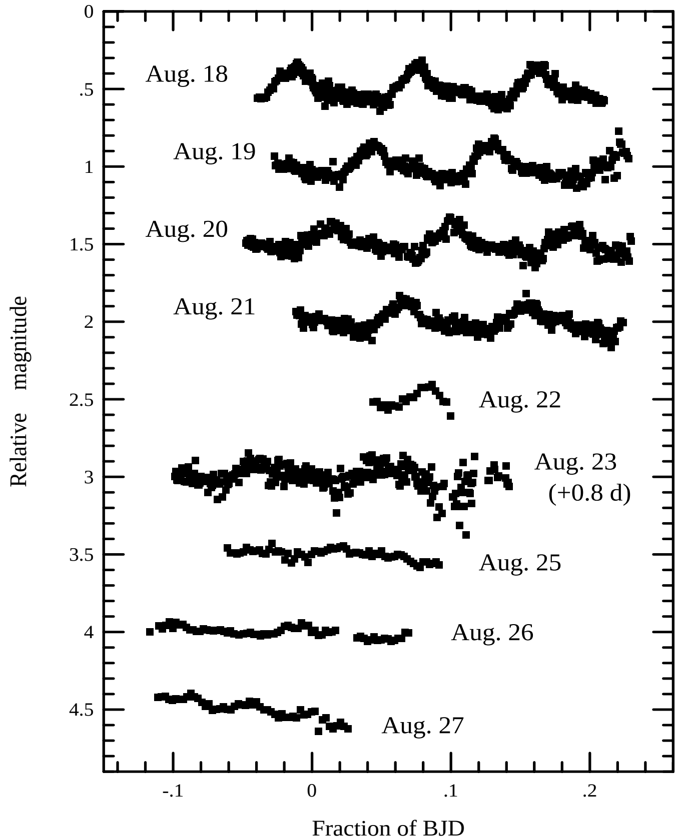

Figure 2. Nightly light curves of BF Ara. Superhumps are clearly visible.

From the August 18 observations by GB and PN, unmistakable superhumps were detected (vsnet-alert 7450)[3], qualifying BF Ara as a genuine SU UMa-type dwarf nova (see section 3.2 for more details). The journal of the CCD observations is listed in Table 2.

Figure 1 shows the light curve of the outburst based on CCD photometry. The slowly fading (0.10 mag d^{-1}) superoutburst plateau phase and a more rapidly fading phase on August 27 (BJD 2452514) are clearly demonstrated. The plateau phase lasted for 13 d since the start of the outburst. Nightly light curves are presented in Figure 2, demonstrating the clear presence of superhumps.

3.2 Superhump Period

Figure 3 shows the result of a period analysis using Phase Dispersion Minimization (PDM: Stellingwerf 1978) applied to the data set covering the superoutburst plateau (2002 August 18–26), after removing the linear decline trend. The best determined frequency of superhumps is 11.368(2) d^{-1}, corresponding to a mean superhump period of $P_{\rm SH}$ = 0.08797(1) d. The significance of this period is better than 99.99%.

Figure 4 shows the phase-averaged profile of superhumps at the period of 0.08797 d. The rapidly rising and

[3] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert7000/msg00450.html.

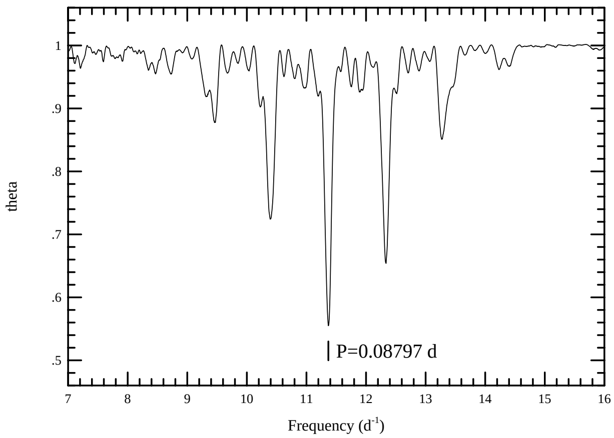

Figure 3. Period analysis of BF Ara. The strongest signal at a frequency of 11.368(2) d^{-1} corresponds to a mean superhump period of $P_{\rm SH}$ = 0.08797(1) d.

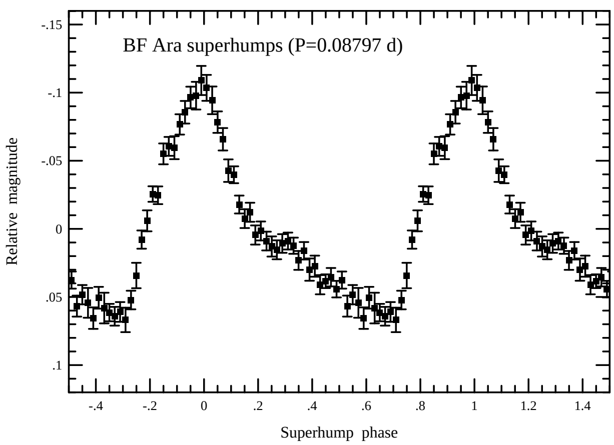

Figure 4. Mean superhump profile of BF Ara.

slowly fading superhump profile is very characteristic of an SU UMa-type dwarf nova (Vogt 1980; Warner 1985).

3.3 Superhump Period Change

We extracted the maximum times of superhumps from the light curve by eye. The averaged times of a few to several points close to the maxima were used as representatives of the maximum times. The errors of the maximum times are less than ~0.002 d. The resultant superhump maxima are given in Table 3. The values are given to 0.0001 d in order to avoid the loss of significant digits in a later analysis. The cycle count (E) is defined as the cycle number since BJD 2452504.990. The maximum at E = 46.5 likely corresponds to a secondary superhump maximum, which is sometimes observed around superhump phases at 0.4–0.6 (Udalski 1990; Kato et al. 1992). The maxima at E = 101.5 and 102.5 correspond to late superhumps (Haefner et al. 1979; Vogt 1983; van der Woerd et al. 1988; Hessman et al. 1992), which are known to have similar periods with ordinary superhumps, but have phases of ~0.5 different from those of ordinary superhumps. Excluding the maxima of the likely secondary superhump and late superhumps, a linear regression to the observed superhump times gives the following ephemeris (the errors correspond to 1σ errors at E = 39):

$$\mathrm{BJD(maximum)} = 2452504.9902(5) + 0.087917(15)E. \quad (1)$$

The derived $O-C$'s against equation 1 are almost zero within the expected errors of the maximum times (Figure 5). A quadratic fit yielded a period derivative of $\dot{P} = -0.6\pm1.2 \times 10^{-6}$ d cycle^{-1}, or $P_{\rm dot} = \dot{P}/P = -0.8\pm1.4 \times 10^{-5}$. This virtually zero period derivative makes a clear contrast against recently discovered SU UMa-type dwarf novae (V877

Table 3. Times of superhump maxima of BF Ara.

E^a	BJD−2400000	$O-C^b$
0	52504.9903	0.0001
1	52505.0762	−0.0019
2	52505.1627	−0.0033
12	52506.0453	0.0001
13	52506.1314	−0.0017
14	52506.2231	0.0021
23	52507.0149	0.0026
24	52507.1034	0.0032
25	52507.1898	0.0017
35	52508.0682	0.0009
36	52508.1557	0.0005
46.5^c	52509.0837	0.0054
60	52510.2636	−0.0016
61	52510.3512	−0.0019
80	52512.0202	−0.0033
90	52512.9027	0.0000
91	52512.9924	0.0018
101.5^d	52513.9127	−0.0011
102	52513.9587	0.0010
102.5^d	52513.9995	−0.0022

^{a} Cycle count since BJD 2452504.990.
^{b} $O-C$ calculated against equation 1.
^{c} Likely secondary superhump maximum.
^{d} Late superhumps.

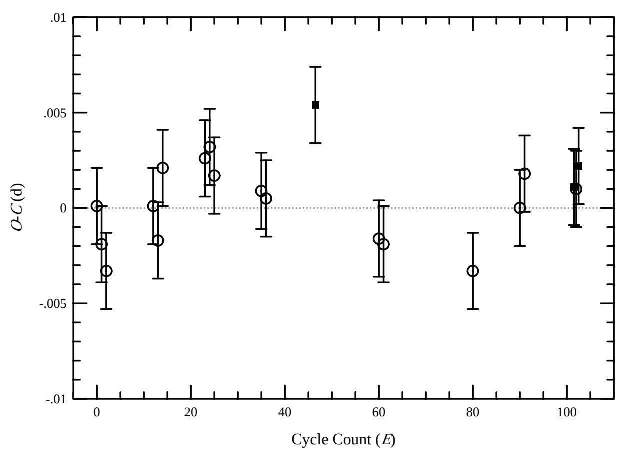

Figure 5. $O-C$ diagram of superhump maxima of BF Ara. The error bars correspond to the upper limits of the errors. The open circles denote (usual) superhumps. The filled squares represent secondary superhump maximum (E = 46.5) and late superhumps (E = 101.5 and E = 102.5). The $O-C$'s are virtually zero, indicating an exceptionally small period derivative.

Ara, KK Tel), which have large negative period derivatives (Kato et al. 2002).

4 ASTROMETRY AND QUIESCENT IDENTIFICATION

The quiescent counterpart of BF Ara has been suggested by Vogt & Bateson (1982). Since this field is very crowded, we have tried to make an unambiguous independent identification based on outburst CCD images.

Astrometry of the outbursting BF Ara was performed on CCD images taken by GB and PN. An average of measurements of seven images (UCAC1 system, 60 – 240 reference stars; internal dispersion of the measurements was $\sim 0''.08$) has yielded a position of $17^h\ 38^m\ 21^s.322$, $-47°\ 10'\ 41''.46$ (J2000.0). The position agrees with the GSC−2.2.1 star at $17^h\ 38^m\ 21^s.307$, $-47°\ 10'\ 41''.10$ (epoch 1996.680 and magnitude $r = 17.67$), which is most likely the quiescent counterpart of BF Ara (Figure 6). Comparing with our position and the oldest DSS image (epoch = 1979.367), no apparent proper motion was detected; its upper limit is deduced to be $0''.03$ yr^{-1}. Note that the DSS red image taken on 1998 June 17 happened to catch BF Ara in outburst.

The Astrographic Catalog (AC) contains an object about 2 arcseconds from BF Ara. The position in the latest version of AC is $17^h\ 38^m\ 21^s.376$, $-47°\ 10'\ 39''.31$ (J2000.0, epoch=1904.644 and magnitude b=13.11). In case it was really BF Ara in outburst, the deduced proper motion is $\sim 0''.022$ yr^{-1}.

5 BF ARA AS AN SU UMA-TYPE DWARF NOVA

Our observations have clearly established that BF Ara is indeed an SU UMa-type dwarf nova. This classification finally enables us to unambiguously determine the outburst types and supercycle length. Figure 7 shows a long-term light curve covering the interval 1997 June – 2002 October.

Table 4 lists the recorded outbursts of BF Ara. The table is an updated extension of the table in Kato et al. (2001), who only listed superoutburst candidates which had been recorded at that time. The durations generally correspond to the durations when the variable was brighter than 15.0 mag. The durations of single or a few solitary observations have been supplemented with an uncertainty mark (:). The durations of outbursts have a clear bimodal ($\leq$2 d or $\geq$7 d) distribution, which is very characteristic of an SU UMa-type star (Vogt 1980; Warner 1985). The type identification of the outbursts was primarily based on their durations.

Since the occurrence of superoutbursts is quite regular (Kato et al. 2001), we have made a reanalysis of the supercycle length based on the new material. A linear regression to the observed start times of supermaxima gives the following ephemeris:

$$\mathrm{JD(maximum)} = 2450632.4 + 84.34 E_O, \qquad (2)$$

where E_O denotes the number of supercycles since the first (JD 2450626.9) superoutburst. The refined mean supercycle length is 84.3(3) d. The $O-C$'s against this equation are displayed in Figure 8. The $|O-C|$'s are usually within

Table 4. List of Outbursts of BF Ara.

JD start[a]	JD end[a]	Max	Duration (d)	Type
50626.9	50636.9	13.9	>10	super
50695.9	50696.9	14.1	2	normal
50707.9	50708.9	14.1	2	normal
50721.9	50731.9	13.8	10	super
50748.0	–	14.2	1	normal
50890.3	50900.2	14.0	>11	super
50937.9	–	14.4	1:	normal
50965.0	–	14.3	1:	normal
50979.9	50992.1	14.1	13	super
51008.9	51010.0	15.0	2	normal
51041.9	–	14.4	1:	normal
51054.9	51071.9	14.0	17	super
51096.9	51097.9	15.0	2	normal
51229.2	51236.3	13.8	>7	super
51251.2	–	14.4	1	normal
51265.3	–	14.6	1	normal
51280.1	51281.3	14.6	2	normal
51290.1	51291.2	14.6	2	normal
51301.2	51321.3	14.2	17	super
51325.3	–	14.8	1:	normal
51353.0	51353.3	14.3	1:	normal
51363.9	–	15.1	1:	normal
51391.9	51400.9	14.1	>9	super
51428.0	51428.9	14.1	1:	normal
51447.9	–	14.2	1:	normal
51458.0	51460.0	14.1	2	normal
51466.0	51473.9	13.9	>8	super
51484.9	–	14.6	1:	normal[b]
51490.9	–	15.0	1:	normal
51587.1	–	14.8	1	normal
51606.3	–	15.0	1:	normal
51616.3	–	14.8	1:	normal
51631.1	51632.3	14.4	2	normal
51640.3	51651.3	14.0	>11	super
51663.1	–	14.9	1:	normal
51685.2	–	14.8	1	normal
51700.0	51701.1	14.7	2	normal
51718.3	51719.0	14.2	1	normal
51724.9	51738.0	14.2	>14	super
51762.0	–	14.8	1:	normal
51785.0	–	14.8	1:	normal
51802.9	–	14.8	1:	normal
51811.9	51821.0	13.9	>9	super
51966.1	51967.3	14.4	2	normal
51975.2	51992.1	14.2	17	super
52044.0	–	15.0	1	normal
52057.1	52070.9	14.2	13	super
52163.0	–	15.0:	1:	normal
52192.0	–	14.8	1:	normal
52373.1	52374.1	14.3	1	normal
52399.0	52400.0	14.4	1	normal
52410.2	52418.3	14.0	>8	super
52428.0	–	14.9	1	normal
52440.2	–	14.6	1:	normal
52485.9	52487.9	14.4	2	normal
52500.9	52513.9	13.9	13	super
52519.0	–	14.9	1	normal
52524.9	52525.9	15.0	2	normal

[a] JD−2400000.
[b] Continuation of the preceding superoutburst?

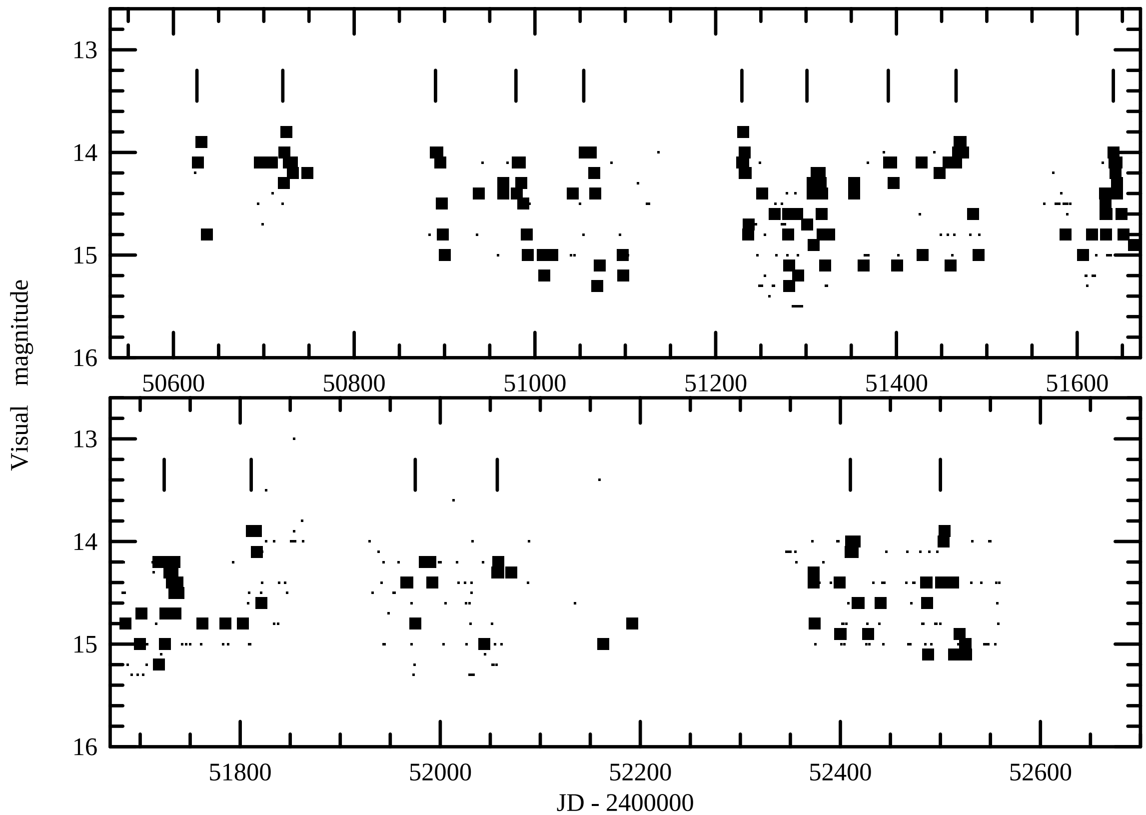

Figure 7. Long-term visual light curve of BF Ara. The large and small dots represent positive and negative (upper limit) observations, respectively. The superoutbursts (see Table 4) are marked with the vertical ticks.

10 d. The small $|O - C|$ values are almost comparable to those of ER UMa stars (Honeycutt et al. 1995; Robertson et al. 1995; Kato 2001), although the short-term stability of the supercycle is not as marked as in ER UMa stars.

6 RELATION TO ER UMA STARS

In addition to short T_s, ER UMa stars have distinct outburst properties. They can be summarized as: (1) extremely short (∼4 d) recurrence time of normal outbursts, (2) extremely large (0.30–0.45) duty cycles of superoutbursts (see folded figures in Robertson et al. 1995; Kato 2001) (3) low outburst amplitudes (2–3 mag). These properties are the natural consequences from the disk-instability model in high-$\dot{M}$ systems (Osaki 1995a). These properties can thus be reasonably used to discriminate ER UMa stars from (a larger population of) SU UMa-type dwarf novae.

In the case of BF Ara, the shortest observed intervals (see Table 4) of normal outbursts was 6 d, although most of the shortest intervals are close to 10 d. These values more resemble those of usual SU UMa-type dwarf novae with the shortest recurrence times.[4] The durations of the well-observed superoutbursts were typically 11–17 d (Table 4). The detailed CCD observation of the 2002 August superoutburst (the duration being 13 d) is in agreement with these estimates. These values correspond to superoutburst duty cycles of 0.13–0.20, which are noticeably smaller than those of ER UMa stars.

Some properties of the superoutburst of BF Ara are also unlike those of ER UMa stars. The mean decline rate (0.10 mag d^{-1}) of the superoutburst plateau (cf. section 3.1) is also close to those of usual SU UMa-type stars (Kato et al. 2002), rather than an extremely small value of ∼0.04 mag d^{-1} in ER UMa (Kato & Kunjaya 1995). The evolution of superhumps (section 3.2) is also quite normal for a usual SU UMa-type dwarf nova with smoothly decaying amplitudes of superhumps, in contrast to ER UMa stars which show a rapid initial decay of the superhump amplitudes and a later regrowth (Kato et al. 1996).

These features indicate that BF Ara should be classified as a usual SU UMa-type dwarf nova rather than an ER UMa star. BF Ara is thus qualified as a usual SU UMa-type dwarf nova with the shortest measured T_s. Despite the past and present intensive studies of the most promising candidates of transitional objects, there still remains an unfilled gap of distributions between ER UMa stars and usual SU UMa-type dwarf novae.

7 ON THE SUPERHUMP PERIOD CHANGE

The periods of "textbook" superhumps in usual SU UMa-type dwarf novae are known to decrease at a rather common rate of $\dot{P}/P \sim -5\times10^{-5}$ during superoutbursts (e.g. Warner 1985; Patterson et al. 1993; for a recent progress, see Kato

[4] The exact conclusion would await further dense, deep observations, since some of the faint, short, normal outbursts could have easily escaped from detection in the present study.

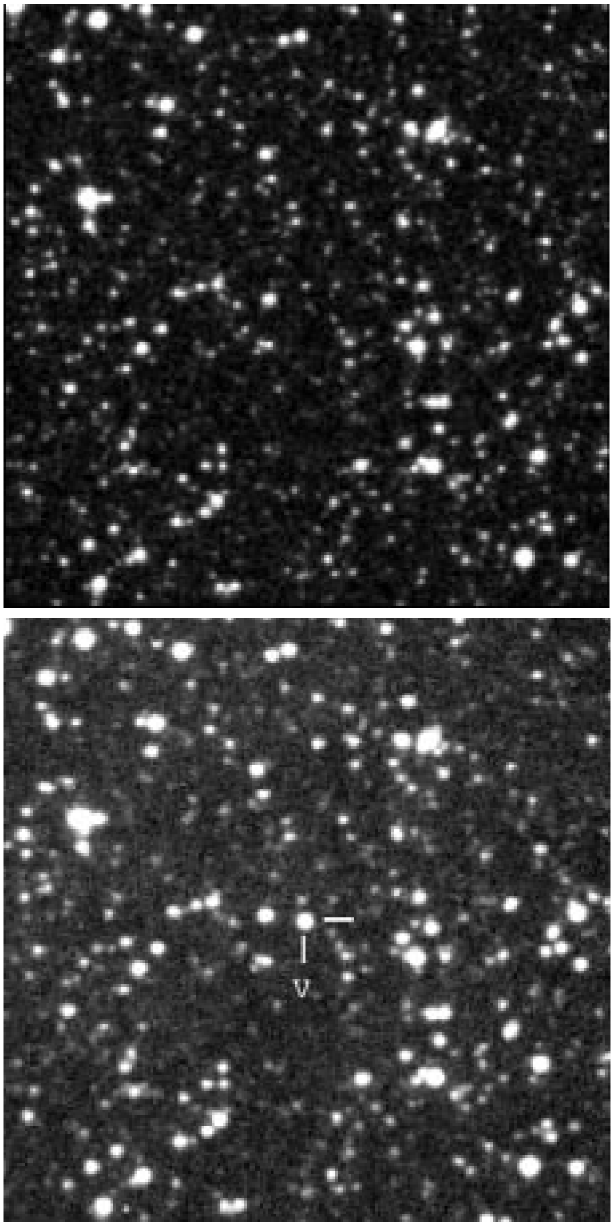

Figure 6. Identification of BF Ara. 5 arcminutes square, north is up and left is east for each image. (Upper:) In quiescence, reproduced from the DSS 2 red image taken on 1996 Sept. 6. (Lower:) In outburst, taken on 2002 August 18 by PN. V = BF Ara.

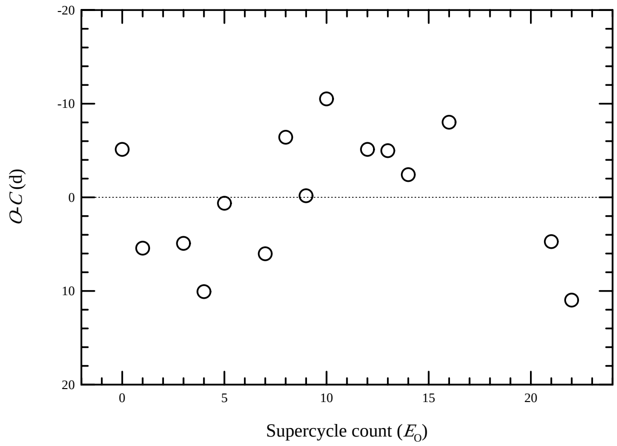

Figure 8. $O-C$ diagram of supermaxima of BF Ara. The $O-C$'s were calculated against equation 2.

et al. 2002). This decrease of the superhump periods has usually been attributed to a decrease in the angular velocity of precession of an eccentric disk, which is caused by a decrease in the disk radius during superoutbursts (Osaki 1985).

In recent years, however, several systems have been found to show zero to positive (increase of the periods) period derivatives. The best-established examples include WZ Sge-type dwarf novae (SU UMa-type dwarf novae with very infrequent (super)outbursts, see e.g. Bailey 1979; Downes & Margon 1981; Patterson et al. 1981; O'Donoghue et al. 1991; Kato et al. 2001) and related large-amplitude systems (V1028 Cyg: Baba et al. 2000; SW UMa: Semeniuk et al. 1997; Nogami et al. 1998; WX Cet: Kato et al. 2001). Since all of these objects have short orbital periods, small q, and small $\dot{M}$, there has been a suggestion that either q or low $\dot{M}$ is responsible for the period increase (Kato et al. 2001). The most recent discoveries of long-period (thus likely large q), and likely low-$\dot{M}$ SU UMa-type dwarf novae (V725 Aql: Uemura et al. 2001; EF Peg: K. Matsumoto et al, in preparation, see also Kato 2002), having zero or marginally positive $P_{\rm dot}$, have more preferred the interpretation requiring a low $\dot{M}$.

The present discovery of a virtually zero $\dot{P}$ in a long-period ($P_{\rm SH}$ = 0.08797(1) d), otherwise relatively normal, system is therefore surprising. This discovery has not only strengthened the previously neglected diversity of $P_{\rm dot}$ in long-period SU UMa-type systems claimed in Kato et al. (2002), but also provides a new clue to understand the physics of superhump period changes.

Since BF Ara has short outburst recurrence times (both superoutbursts and normal outbursts), $\dot{M}$ is expected to high (Ichikawa & Osaki 1994). By using typical supercycles of BF Ara (84.3 d) and V725 Aql (~900 d), the expected $\dot{M}$ in BF Ara is ~10 times larger than that in V725 Aql (Ichikawa & Osaki 1994). The occurrence of nearly zero $P_{\rm dot}$ systems in a wide region of $\dot{M}$ implies that the interpretation requiring a low $\dot{M}$ would be no longer valid, or a different mechanism is responsible for BF Ara. Murray (2000); Montgomery (2001) recently suggested that the (prograde) apsidal motion of the eccentric disk can be reduced by introducing pressure forces. A high $\dot{M}$ in BF Ara may have modified the usual time-evolution of superhump period through this pressure effect. If this is the case, we can expect a more prominent effect in ER UMa stars, although a limited $P_{\rm dot}$ measurement (Patterson et al. 1995) failed to allow us a definitive conclusion. Further observations of $P_{\rm dot}$ in more systems with a wide range of parameters are definitely needed.

ACKNOWLEDGMENTS

This work is partly supported by a grant-in-aid [13640239 (TK), 14740131 (HY)] from the Japanese Ministry of Education, Culture, Sports, Science and Technology. The CCD operation of the Bronberg Observatory is partly sponsored by the Center for Backyard Astrophysics. The CCD operation by Peter Nelson is on loan from the AAVSO, funded by the Curry Foundation. This research has made use of the Digitized Sky Survey producted by STScI, the ESO Skycat tool, the VizieR catalogue access tool.

REFERENCES

Baba H., Kato T., Nogami D., Hirata R., Matsumoto K., Sadakane K., 2000, PASJ, 52, 429

Bailey J., 1979, MNRAS, 189, 41P

Bruch A., 1983, Inf. Bull. Var. Stars, 2286

Buat-Ménard V., Hameury J.-M., 2002, A&A, 386, 891

Buat-Ménard V., Hameury J.-M., Lasota J.-P., 2001, A&A, 366, 612

Downes R. A., Margon B., 1981, MNRAS, 197, 35P

Haefner R., Schoembs R., Vogt N., 1979, A&A, 77, 7

Harvey D., Skillman D. R., Patterson J., Ringwald F. A., 1995, PASP, 107, 551

Hellier C., 2001, PASP, 113, 469

Hessman F. V., Mantel K.-H., Barwig H., Schoembs R., 1992, A&A, 263, 147

Honeycutt R. K., Robertson J. W., Turner G. W., 1995, in Bianchini A., della Valle M., Orio M., eds, Cataclysmic Variables (Dordrecht: Kluwer Academic Publishers), p. 75

Ichikawa S., Osaki Y., 1994, in Duschl W. J., Frank J., Meyer F., Meyer-Hofmeister E., Tscharnuter W. M., eds, Theory of Accretion Disks-2 (Dordrecht: Kluwer Academic Publishers), p. 169

Ishioka R., Kato T., Uemura M., Iwamatsu H., Matsumoto K., Martin B. E., Billings G. W., Novak R., 2001, PASJ, 53, L51

Kato T., 2001, PASJ, 53, L17

Kato T., 2002, PASJ, 54, 87

Kato T., Hanson G., Poyner G., Muyllaert E., Reszelski M., Dubovsky P. A., 2000, Inf. Bull. Var. Stars, 4932

Kato T., Hirata R., Mineshige S., 1992, PASJ, 44, L215

Kato T., Ishioka R., Uemura M., 2002, PASJ, 54, 1029

Kato T., Kunjaya C., 1995, PASJ, 47, 163

Kato T., Lipkin Y., Retter A., Leibowitz E., 1998, Inf. Bull. Var. Stars, 4602

Kato T., Matsumoto K., Nogami D., Morikawa K., Kiyota S., 2001, PASJ, 53, 893

Kato T., Nogami D., Baba H., 1996, PASJ, 48, L93

Kato T., Nogami D., Baba H., Masuda S., Matsumoto K., Kunjaya C., 1999, in Mineshige S., Wheeler J. C., eds, Disk Instabilities in Close Binary Systems (Tokyo: Universal Academy Press), p. 45

Kato T., Nogami D., Masuda S., 1996, PASJ, 48, L5

Kato T., Nogami D., Masuda S., Baba H., 1998, PASP, 110, 1400

Kato T., Nogami D., Masuda S., Hirata R., 1995, Inf. Bull. Var. Stars, 4193

Kato T., Santallo S., Bolt G., Richards T., Nelson P., Monard B., Uemura M., Kiyota S., Stubbings R., Pearce A., Watanabe T., Schmeer P., Yamaoka H., 2003, MNRAS, in press (astro-ph/0210674)

Kato T., Sekine Y., Hirata R., 2001, PASJ, 53, 1191

Kato T., Stubbings R., Nelson P., Santallo R., Ishioka R., Uemura M., Sumi T., Muraki Y., Kilmartin P., Bond I., Noda S., Yock P., Hearnshaw J. B., Monard B., Yamaoka H., 2002, A&A, 395, 541

Kato T., Stubbings R., Pearce A., Dubovsky P. A., Kiyota S., Itoh H., Simonsen M., 2001, Inf. Bull. Var. Stars, 5109

Kato T., Stubbings R., Pearce A., Nelson P., Monard B., 2001, Inf. Bull. Var. Stars, 5119

Kholopov P. N., Samus' N. N., Frolov M. S., Goranskij V. P., Gorynya N. A., Kireeva N. N., Kukarkina N. P., Kurochkin N. E., Medvedeva G. I., Perova N. B., Shugarov S. Y., 1985, General Catalogue of Variable Stars, fourth edition. Moscow: Nauka Publishing House

King A. R., 1988, QJRAS, 29, 1

King A. R., 2000, New Astronomy Reviews, 44, 167

King A. R., Frank J., Kolb U., Ritter H., 1995, ApJ, 444, L37

King A. R., Frank J., Kolb U., Ritter H., 1996, ApJ, 467, 761

Kolb U., Rappaport S., Schenker K., Howell S., 2001, ApJ, 563, 958

McCormick P., 1998, in Howell S., Kuulkers E., Woodward C., eds, ASP Conf. Ser. 137, Wild Stars in the Old West (San Francisco: ASP), p. 415

Misselt K. A., Shafter A. W., 1995, AJ, 109, 1757

Montgomery M. M., 2001, MNRAS, 325, 761

Murray J. R., 2000, MNRAS, 314, 1P

Nogami D., Baba H., Kato T., Novák R., 1998, PASJ, 50, 297

Nogami D., Kato T., 1997, PASJ, 49, 109

Nogami D., Kato T., Masuda S., Hirata R., 1995, Inf. Bull. Var. Stars, 4155

Nogami D., Kato T., Masuda S., Hirata R., Matsumoto K., Tanabe K., Yokoo T., 1995, PASJ, 47, 897

Nogami D., Masuda S., Kato T., 1997, PASP, 109, 1114

O'Donoghue D., Chen A., Marang F., Mittaz J. P. D., Winkler H., Warner B., 1991, MNRAS, 250, 363

Osaki Y., 1985, A&A, 144, 369

Osaki Y., 1989, PASJ, 41, 1005

Osaki Y., 1995a, PASJ, 47, L11

Osaki Y., 1995b, PASJ, 47, L25

Osaki Y., 1996, PASP, 108, 39

Patterson J., 1998, PASP, 110, 1132

Patterson J., Bond H. E., Grauer A. D., Shafter A. W., Mattei J. A., 1993, PASP, 105, 69

Patterson J., Jablonski F., Koen C., O'Donoghue D., Skillman D. R., 1995, PASP, 107, 1183

Patterson J., McGraw J. T., Coleman L., Africano J. L., 1981, ApJ, 248, 1067

Rappaport S., Joss P. C., Verbunt F., 1983, ApJ, 275, 713

Rappaport S., Joss P. C., Webbink R. F., 1982, ApJ, 254, 616

Robertson J. W., Honeycutt R. K., Turner G. W., 1995, PASP, 107, 443

Semeniuk I., Olech A., Kwast T., Nalezyty M., 1997, Acta Astron., 47, 201

Shara M. M., Livio M., Moffat A. F. J., Orio M., 1986, ApJ, 311, 163

Stellingwerf R. F., 1978, ApJ, 224, 953

Udalski A., 1990, AJ, 100, 226

Uemura M., Kato T., Pavlenko E., Baklanov A., Pietz J., 2001, PASJ, 53, 539

van der Woerd H., van der Klis M., van Paradijs J., Beuermann K., Motch C., 1988, ApJ, 330, 911

Vogt N., 1980, A&A, 88, 66
Vogt N., 1983, A&A, 118, 95
Vogt N., Bateson F. M., 1982, A&AS, 48, 383
Warner B., 1985, in Eggelton P. P., Pringle J. E., eds, Interacting Binaries (Dordrecht: D. Reidel Publishing Company), p. 367
Warner B., 1995, Ap&SS, 226, 187